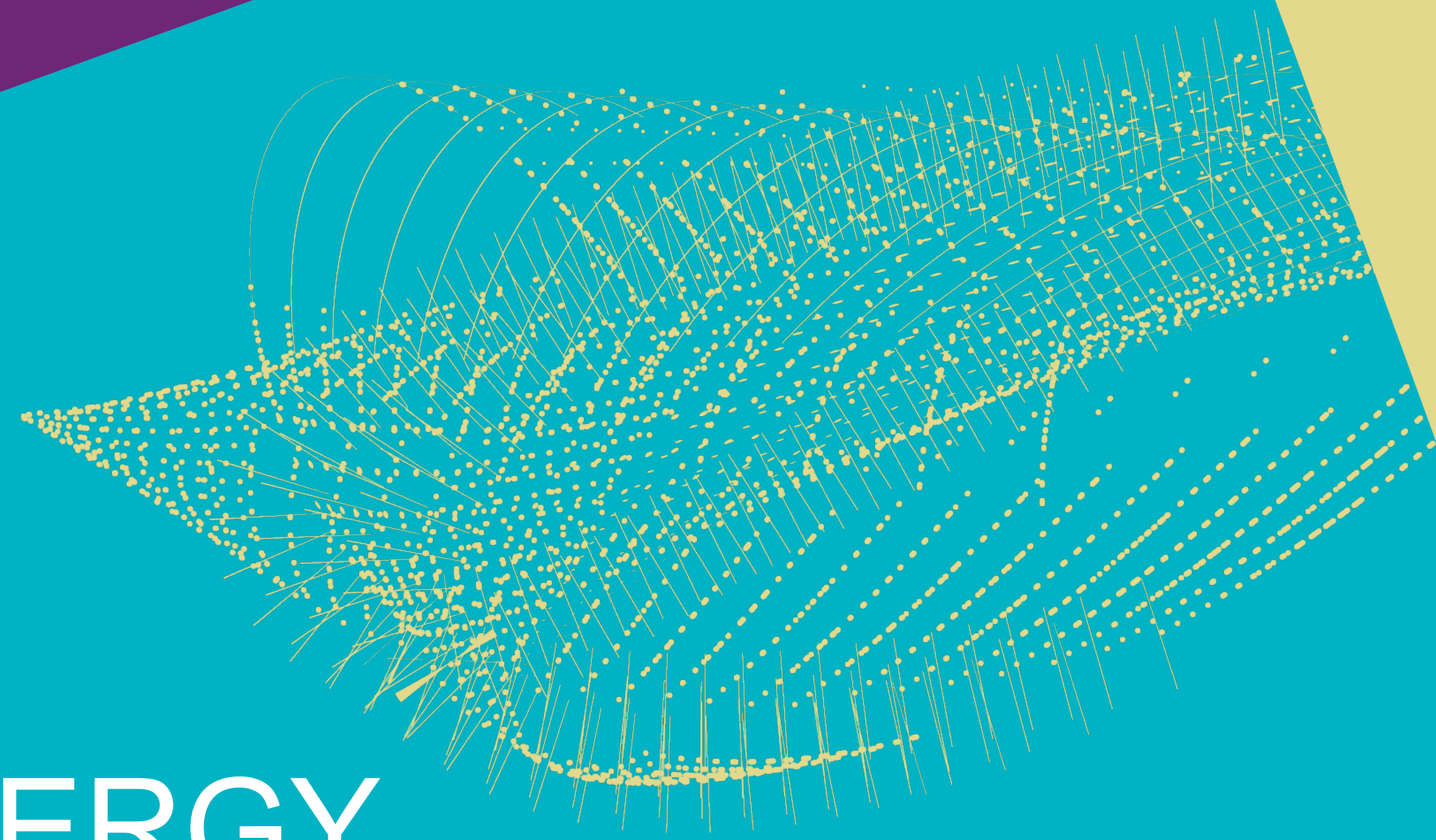


Nikhef



ULTRA-HIGH-ENERGY
COSMIC RAYS

THE GROUP

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- Tomas Fodran (2023)
- Abha Kakurdikar (2024)
- Mohit Saharan (2025)
- Mohamed Emam (2025)
- Anthony Bwembya (2025)



**PARTICLE INTERACTIONS
AT THE HIGHEST ENERGY
EVER SEEN**

**ORIGIN OF HIGHEST-ENERGY
PARTICLES IN THE UNIVERSE**

?

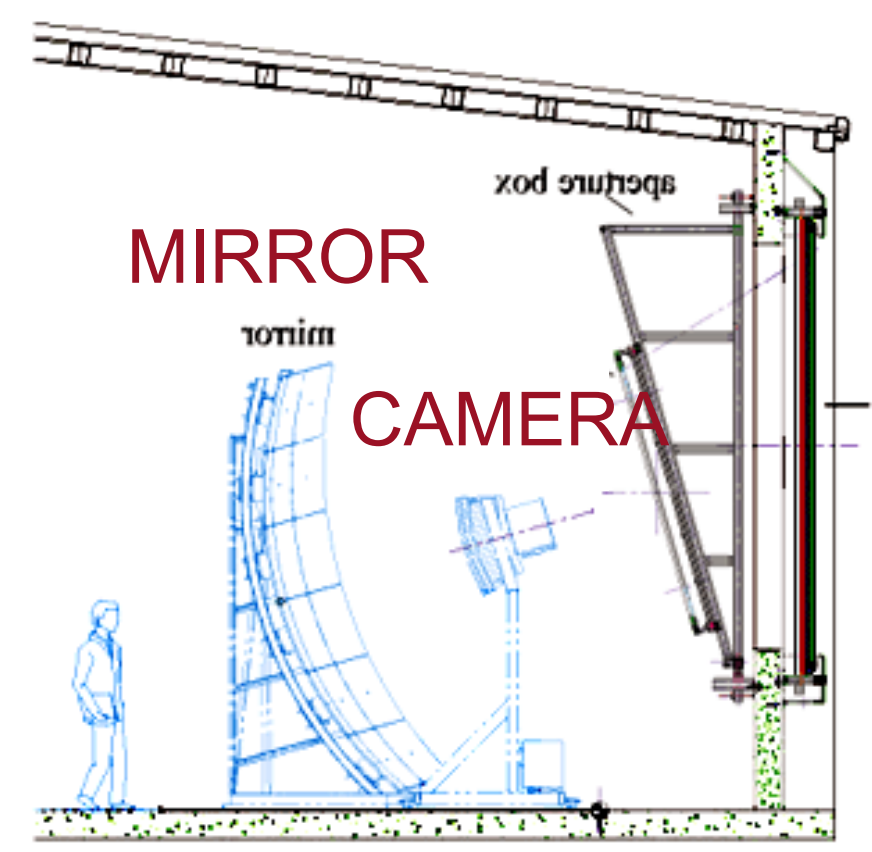
?

PARTICLE TYPE IS THE KEY !

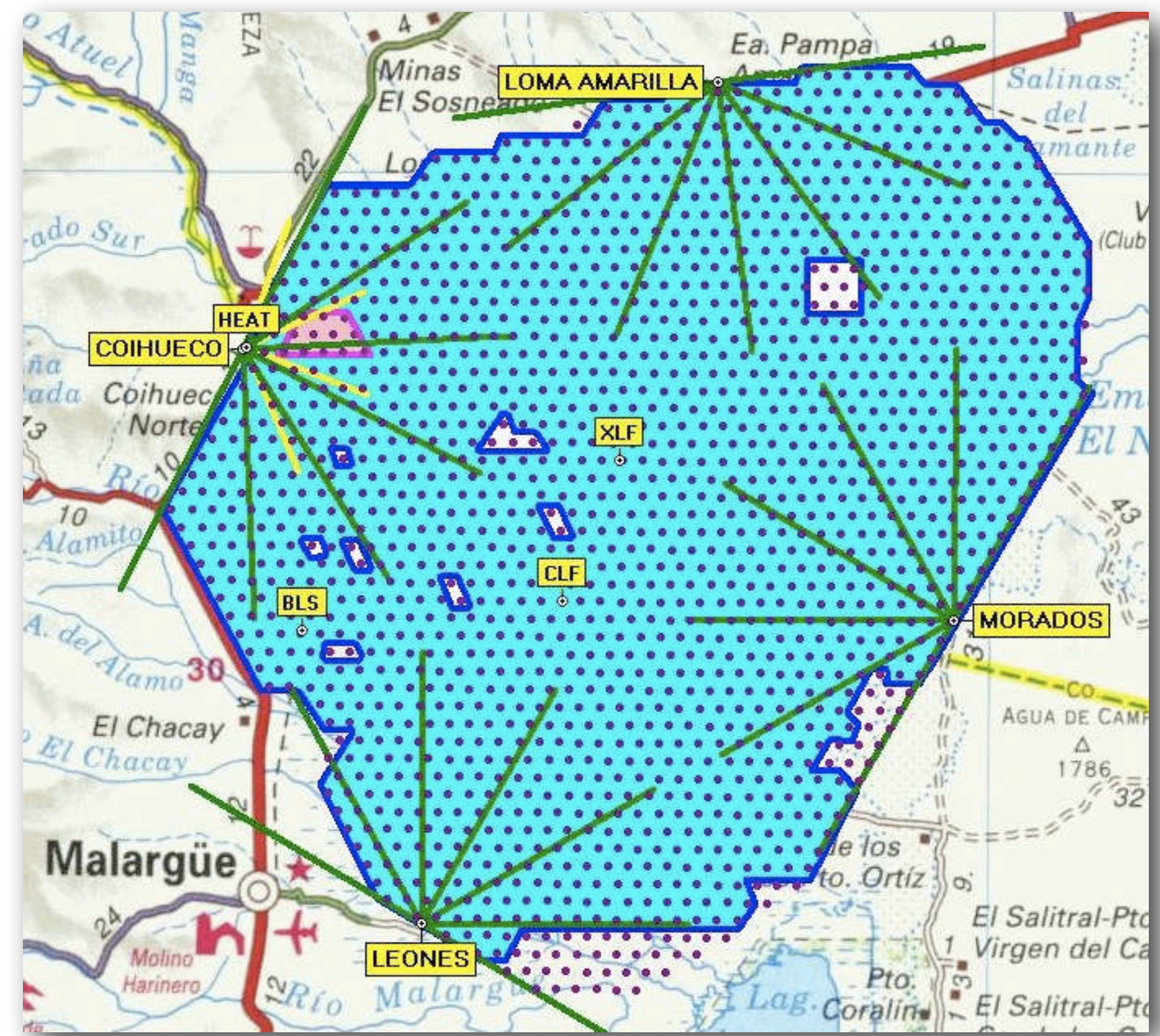
COSMIC RAY

STATE-OF-THE-ART: FD
ENERGY, DIRECTION & PARTICLE
TYPE

X_{MAX} USING FLUORESCENCE LIGHT
 $\Sigma(X_{MAX}) = 20 \text{ G/CM}^2$

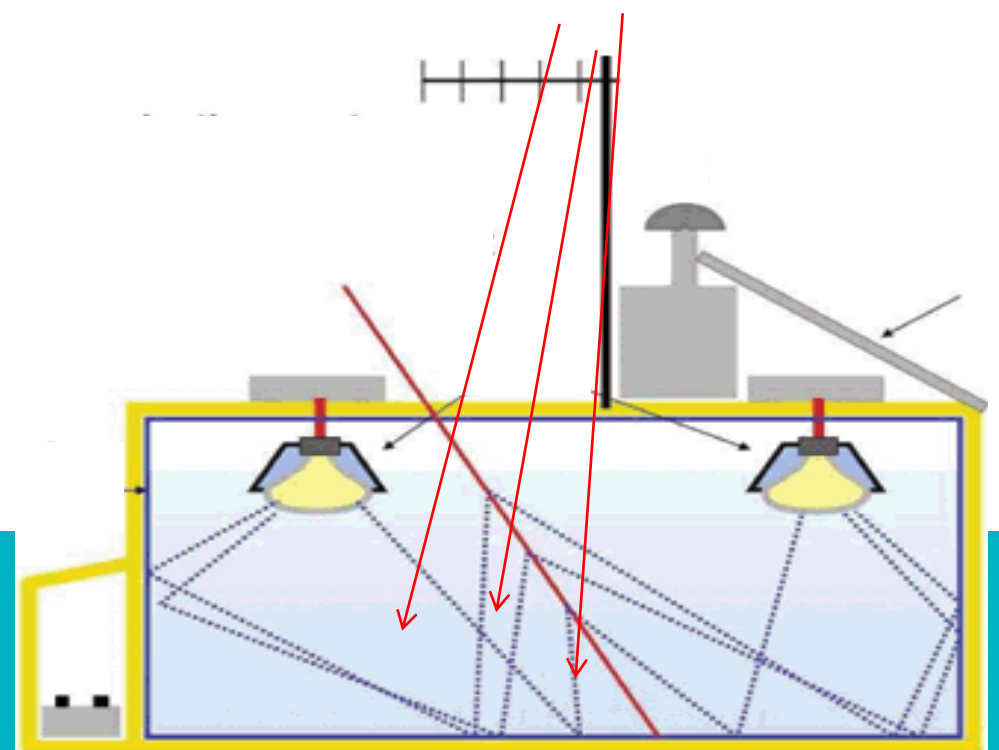


PARTICLES



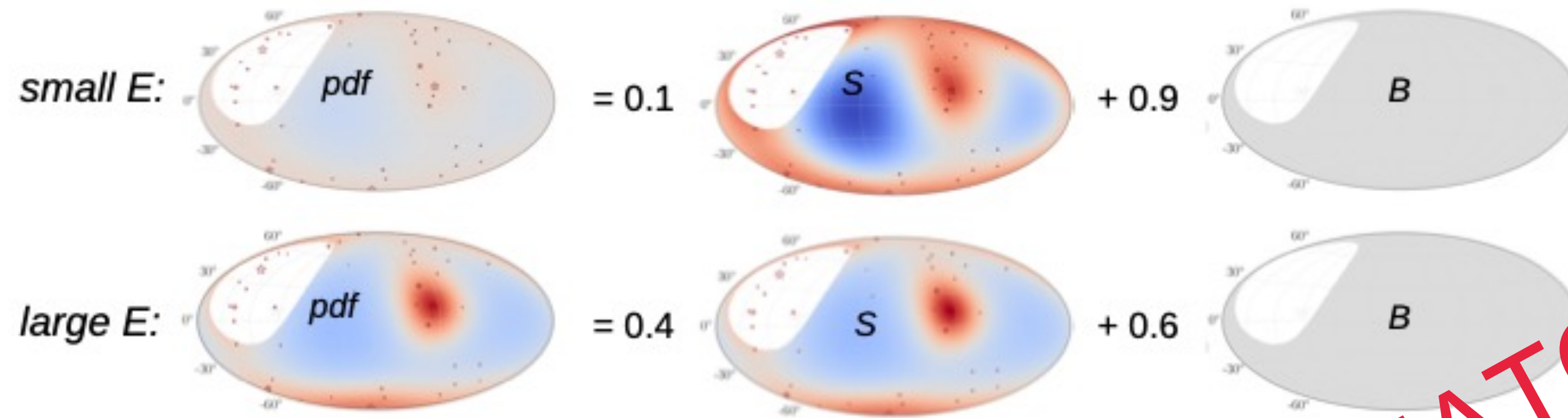
50X60 KM = DUTCH PROVINCE

ONLY IN DARK NIGHTS
10% DUTY CYCLE



AUGER COMBINED FITS

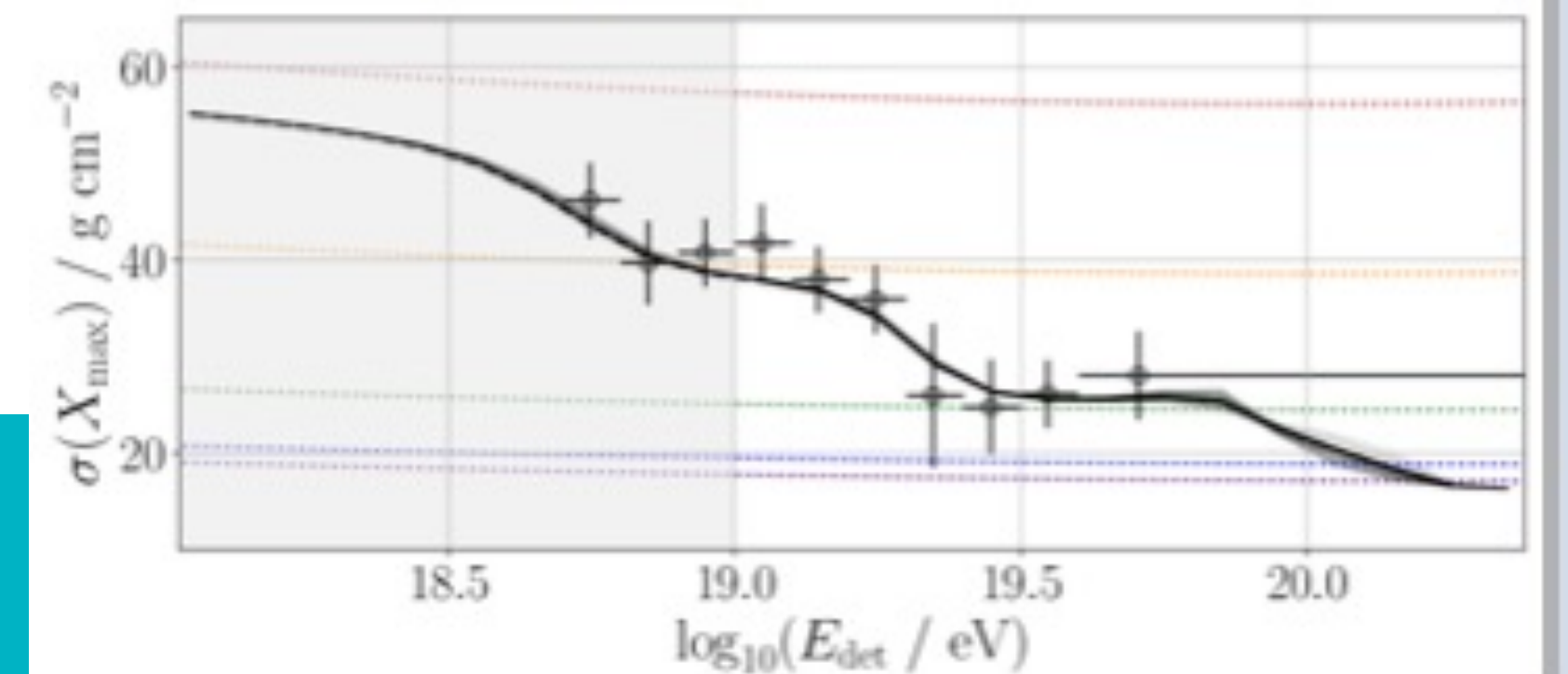
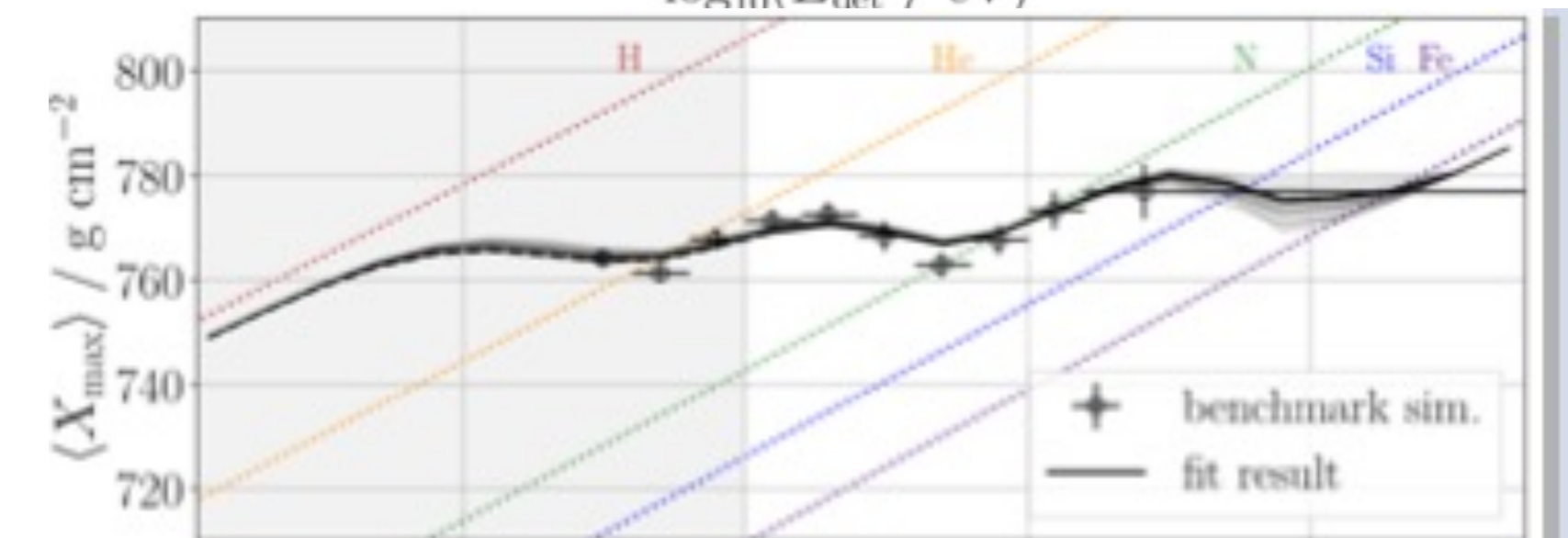
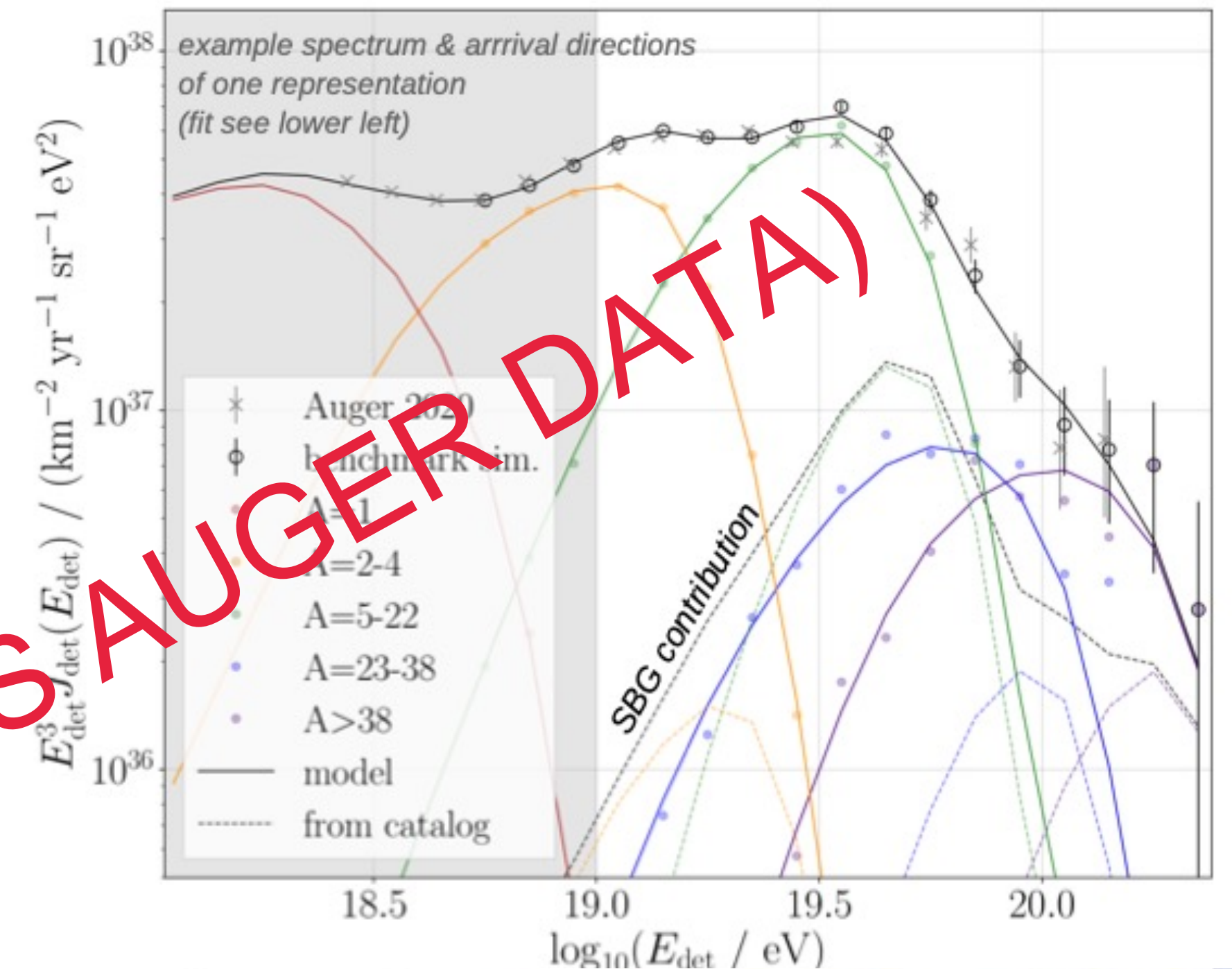
$$\text{pdf}(E_{\text{det}}^e, \text{pix}^p) = f_s(f_0, E_{\text{det}}^e) \cdot S(E_{\text{det}}^e, \text{pix}^p) + (1 - f_s(f_0, E_{\text{det}}^e)) \cdot B(\text{pix}^p)$$



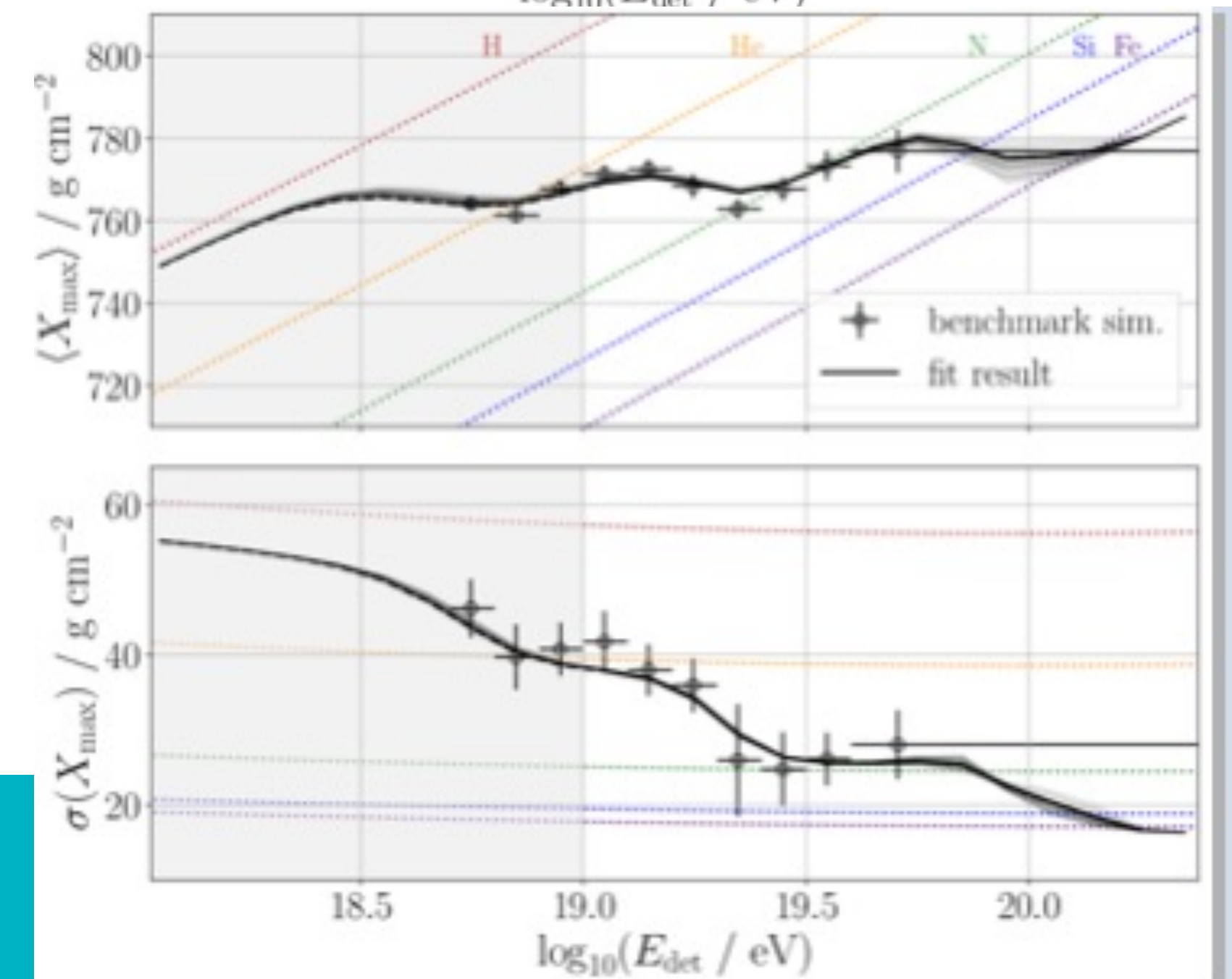
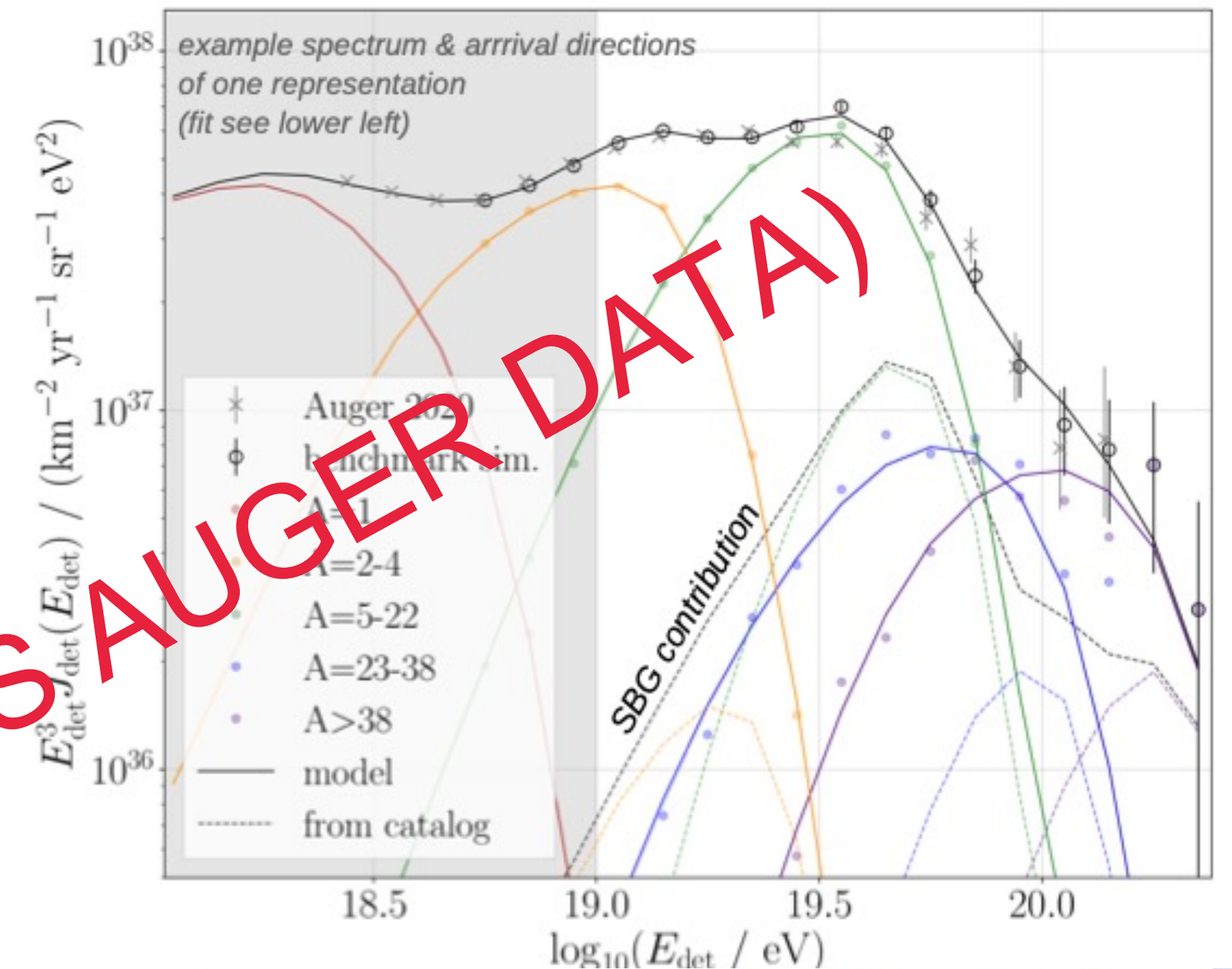
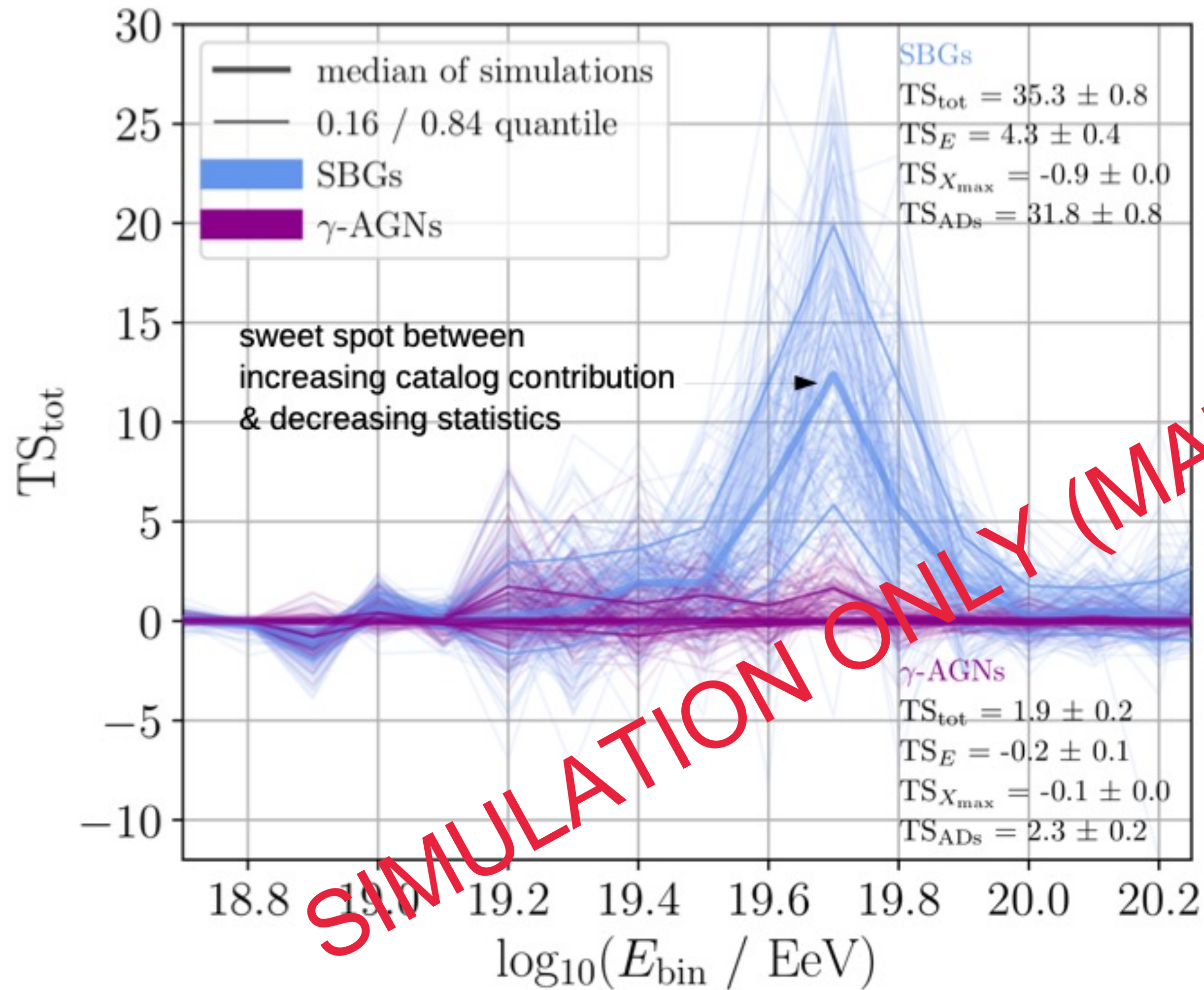
- catalog contribution f_s rises with energy (catalog sources closer)

parameter	γ^{truth}	$\log_{10}(R_{\text{cut}}^{\text{truth}}/V)$	$I_{\text{H}}^{\text{truth}}$	$I_{\text{He}}^{\text{truth}}$	$I_{\text{N}}^{\text{truth}}$	$I_{\text{Si}}^{\text{truth}}$	$I_{\text{Fe}}^{\text{truth}}$	f_0^{truth}	δ_0^{truth}
sim. truth	-3.22	18.09	0%	15%	77%	5.4%	2.6%	0.15	20.0°

SIMULATION ONLY (MATCHES AUGER DATA)



AUGER COMBINED FITS



AUGERPRIME

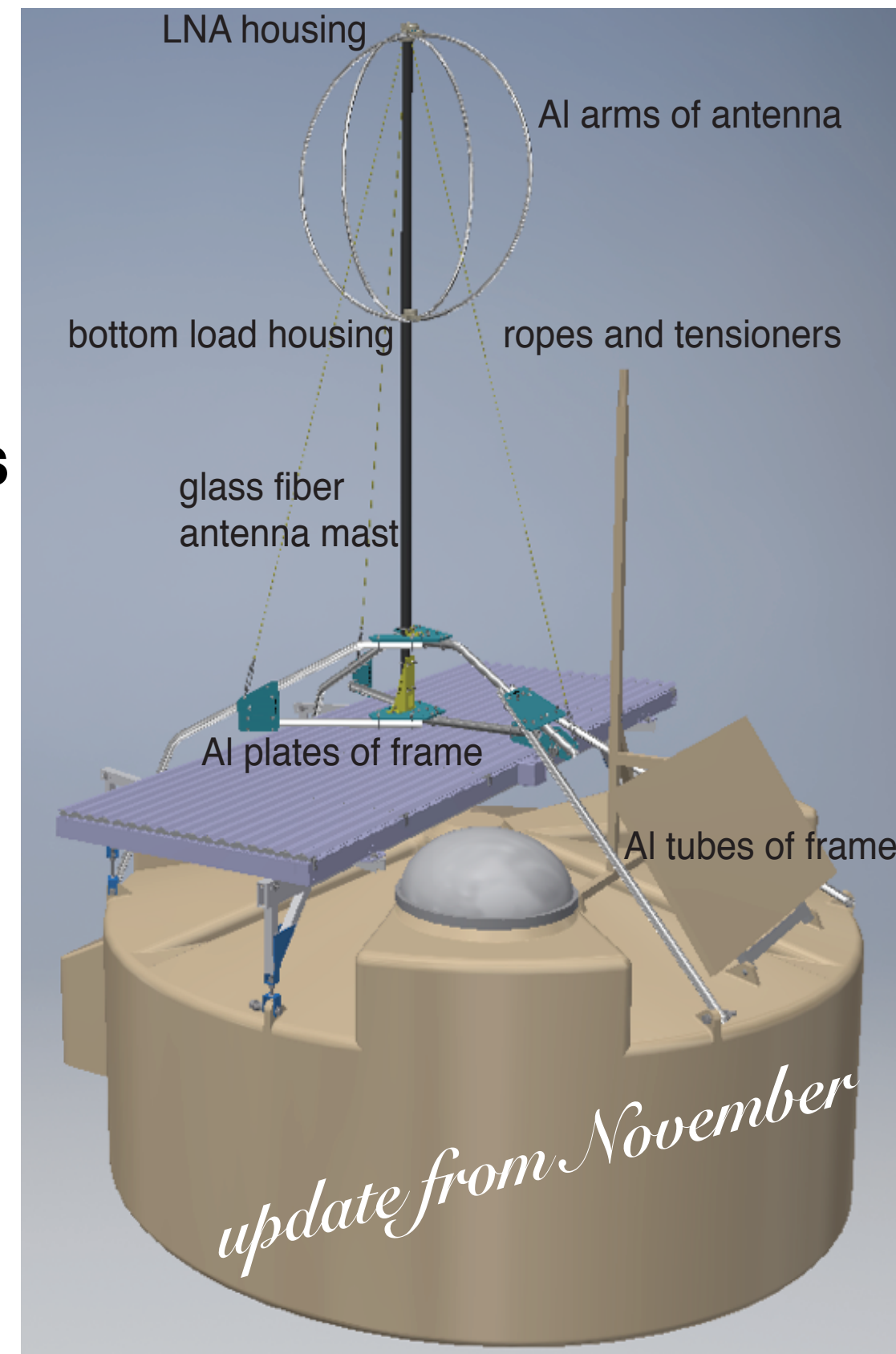
basically all
RD items are already in Malargüe:

- solar panels - 2000 units
- antenna arms - 6800 parts
- ropes (6 km) and tensioners for the mast
- Al tubes for frame - 13600 parts
- Al plates and antenna foot - 8500 parts
- small parts, u-bolts, nuts, screws, ... ~400000 pieces
- housings for digitizers - 2000
- pigtail cables for the LNA - 4000
- housings for LNAs and bottom loads - 12000 parts
- glass fiber antenna masts - 1700
- ferrites - 8500
- mounting brackets for solar panels - 3400 pieces
- L-ground bracket inside the dome - 1700 pieces
- bottom load PCBs - 2000 pieces
- signal cables inside mast - 3400 cables
- fixtures to assemble ferrites - 24 units

→ 6 sea containers, 75 m³ each

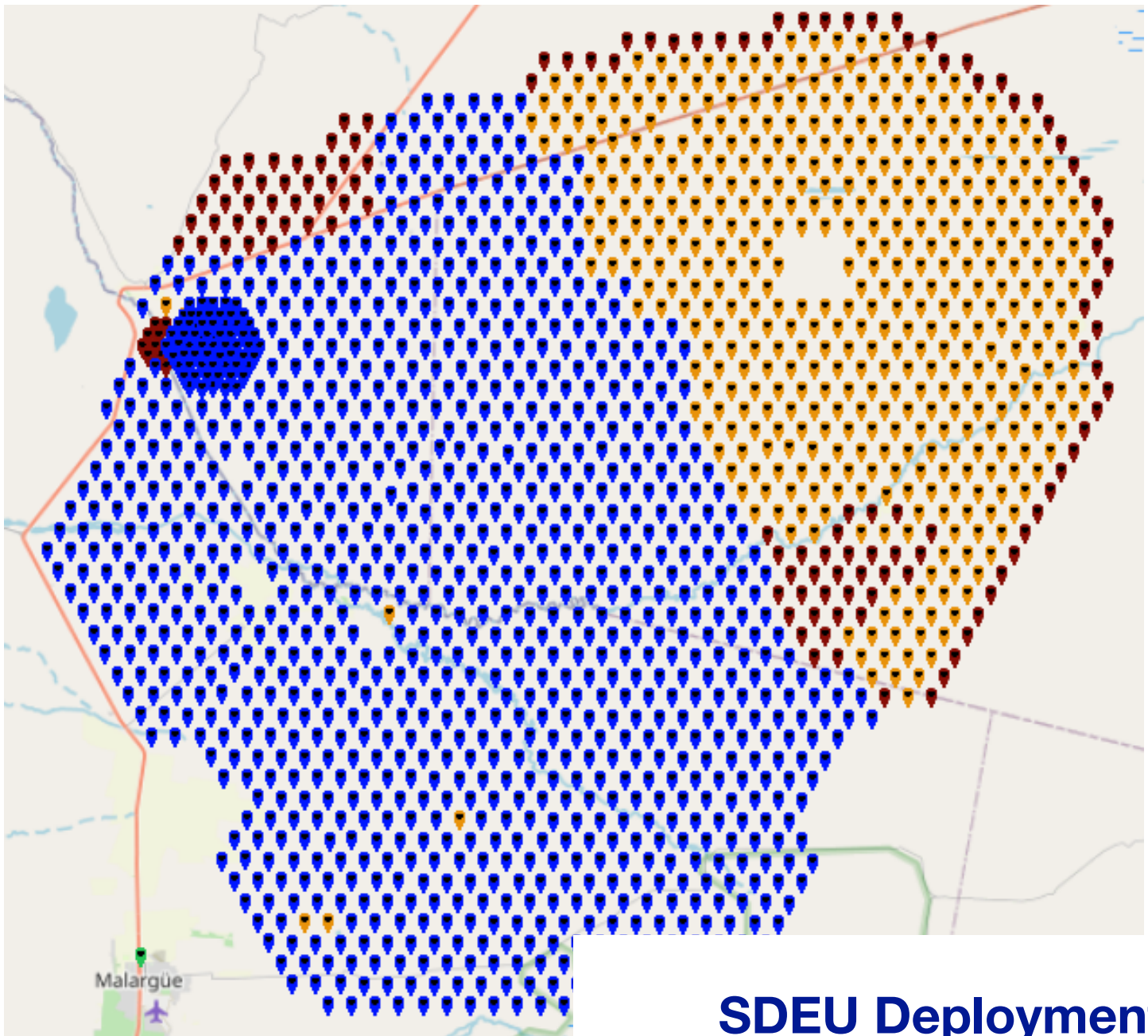
for 1700
stations

RD status



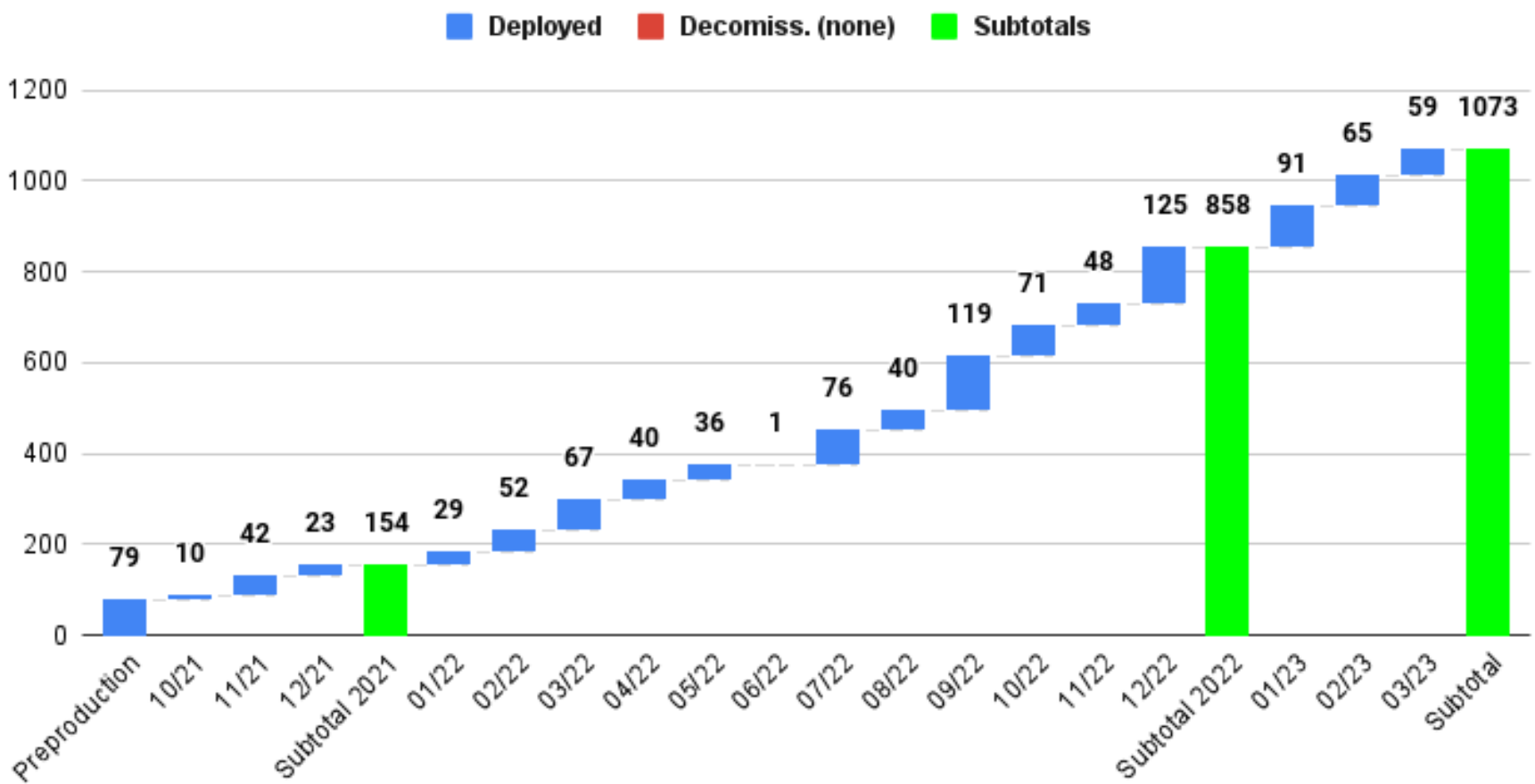
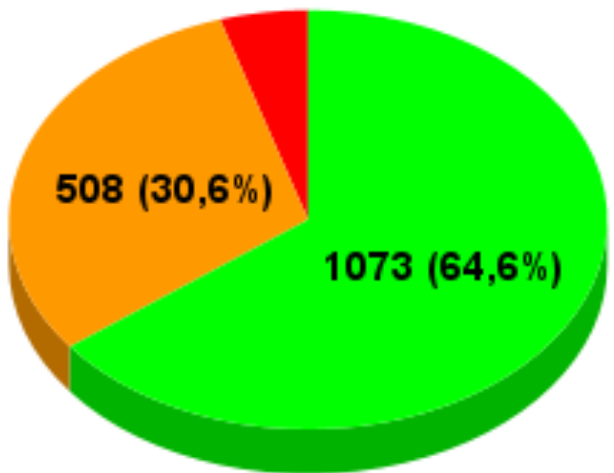
AUGERPRIME

Status of the deployment of UUBs and small PMTs



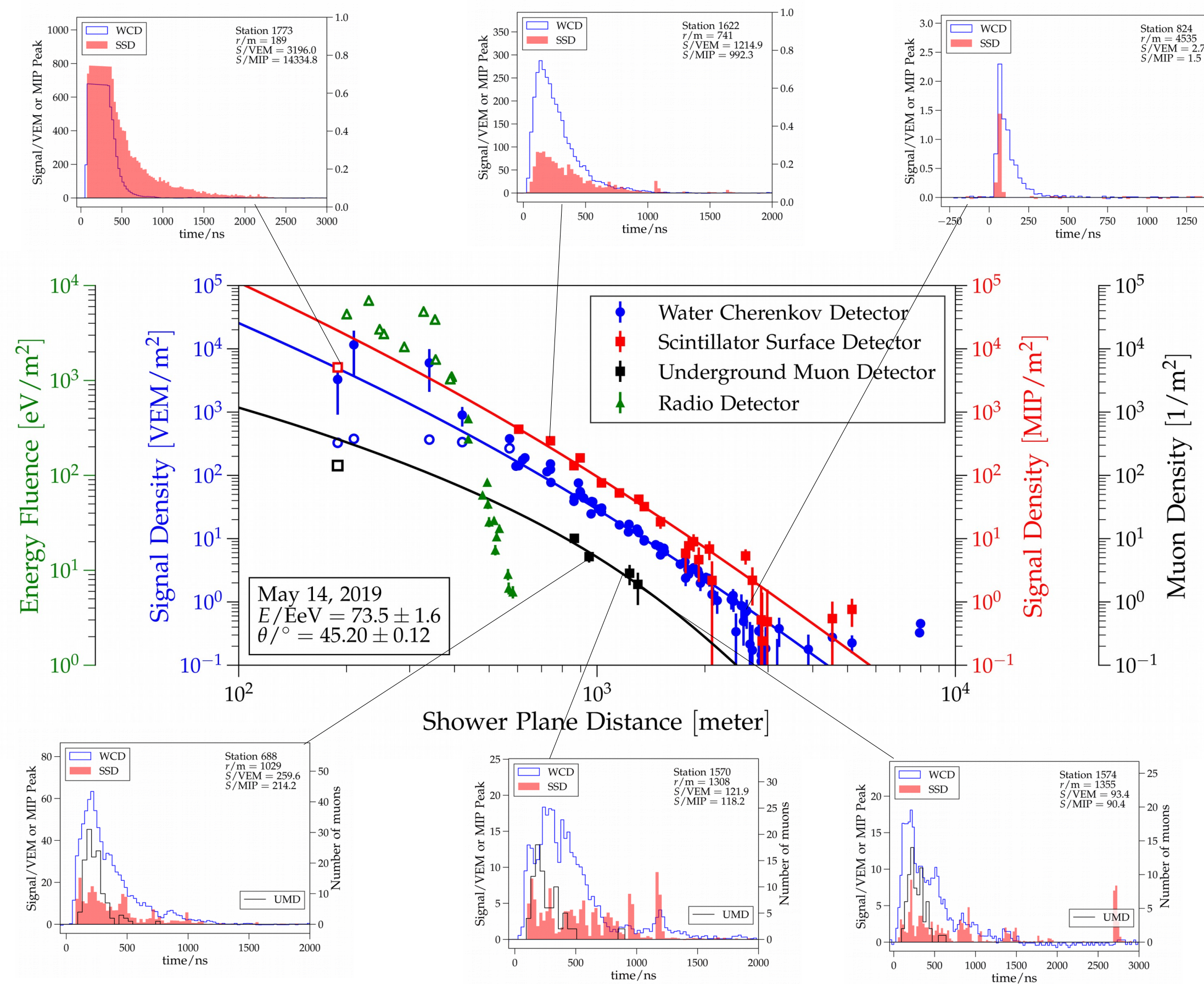
**SDEU Deployment Status
10 March 2023**

- Deployed.
 - To Be Deployed.
 - Not Accessible (79 SD).
- Nominal 1660 SD

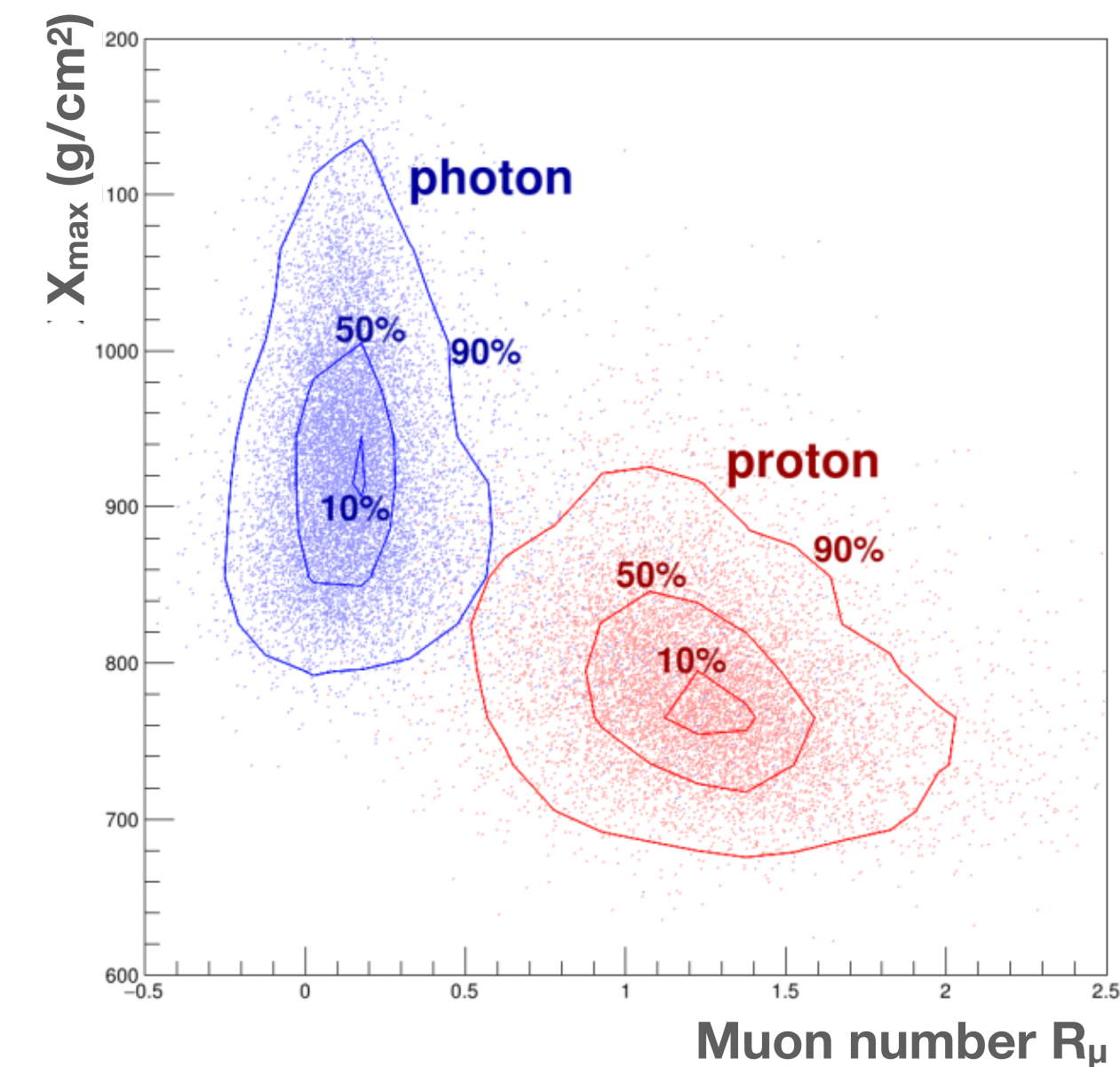


AUGERPRIME DATA

Example of rich information in data of Phase II



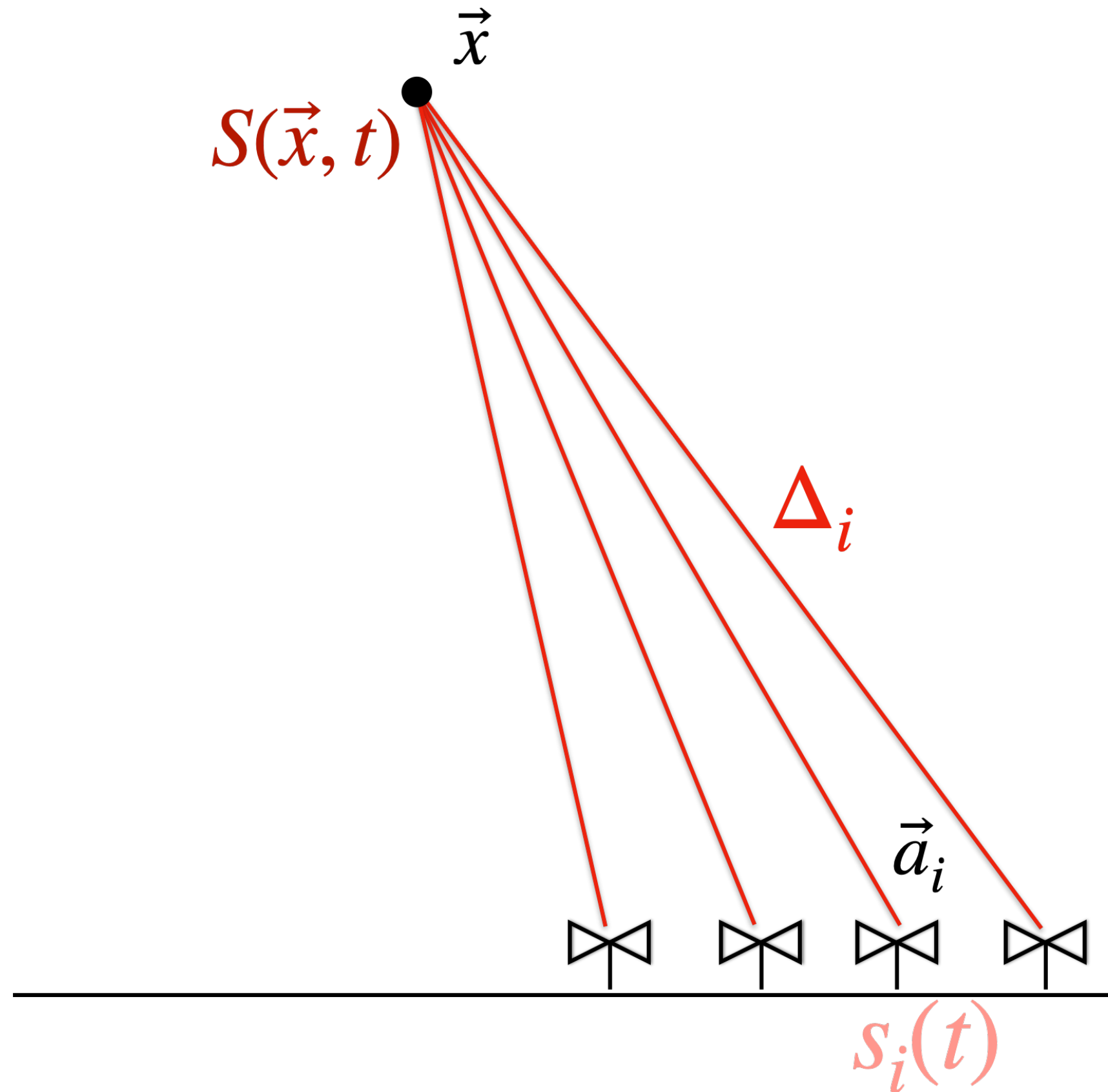
Great physics potential in muons



(Auger, Universe 2022)

RD: INTERFEROMETRY

Concept



Measure signal $s_i(t)$ at location a_i



Calculate light travel time from antenna \vec{a}_i to a location in space \vec{x}

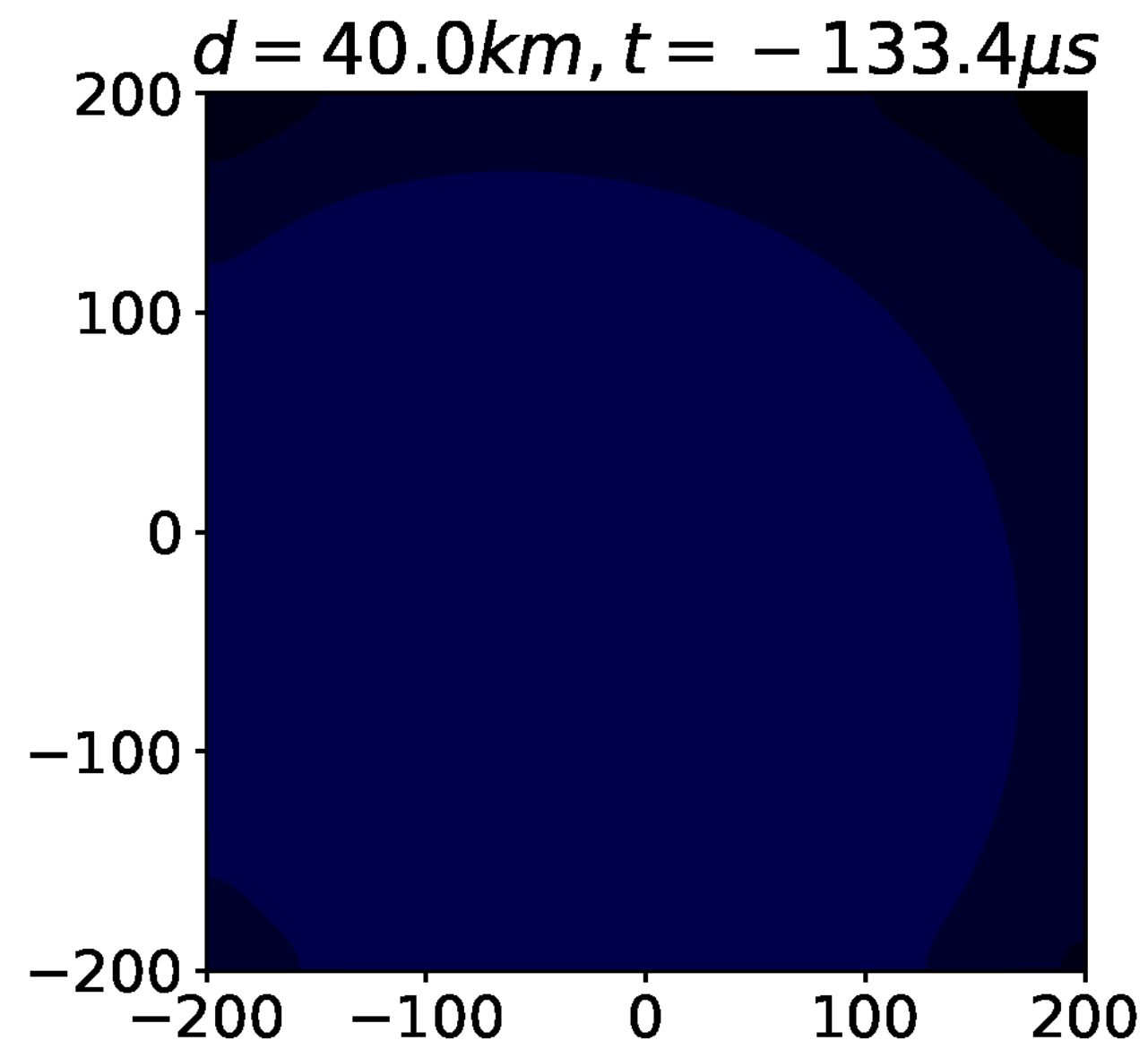
$$\Delta_i(\vec{x}) = \frac{|\vec{x} - \vec{a}_i| n_{eff}}{c}$$

Sum the waveforms from all antennas together with delays $\Delta_i(\vec{x})$ at \vec{x} :

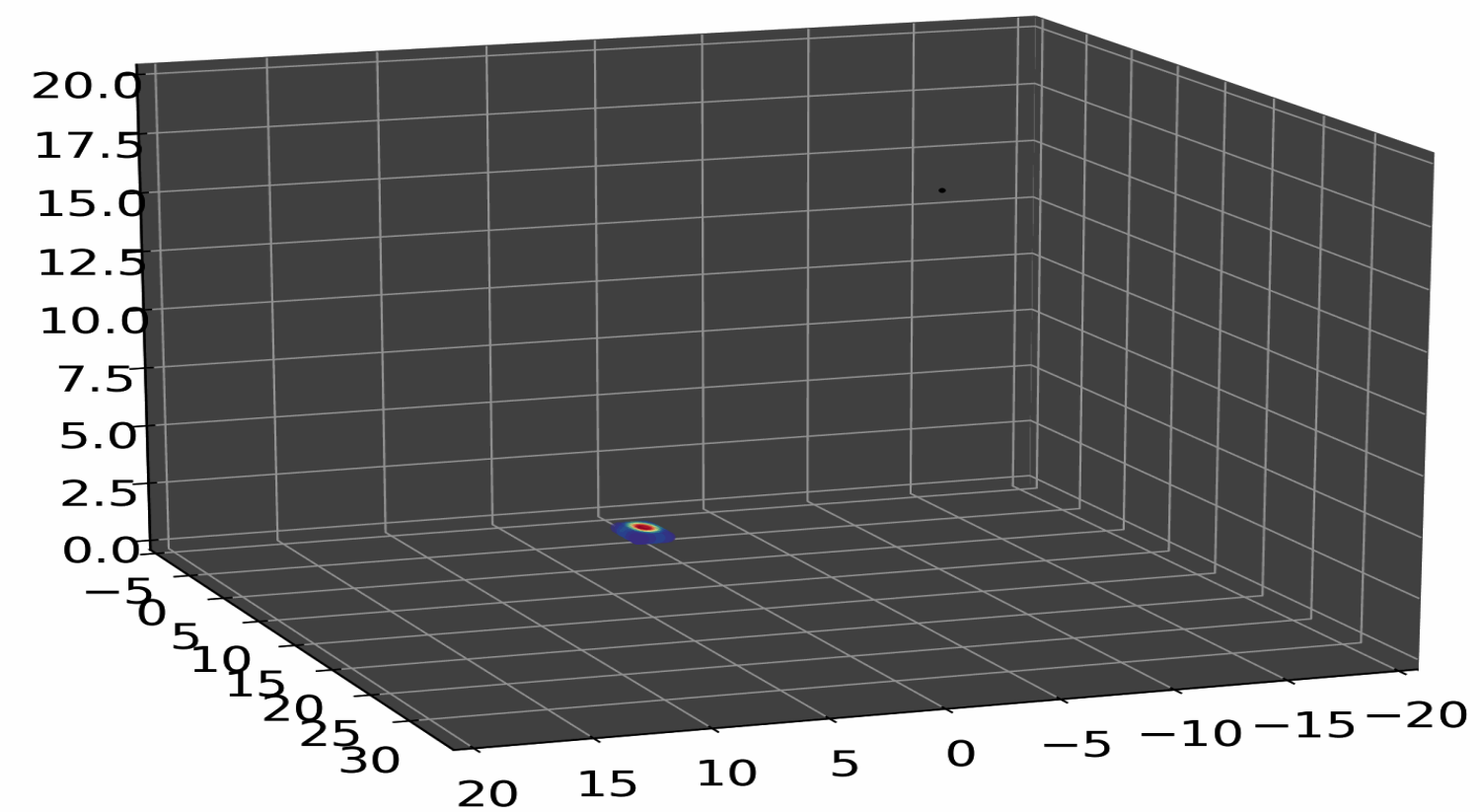
$$S(\vec{x}, t) = \sum_i^N s_i(t + \Delta_i(\vec{x}))$$

RD: INTERFEROMETRY

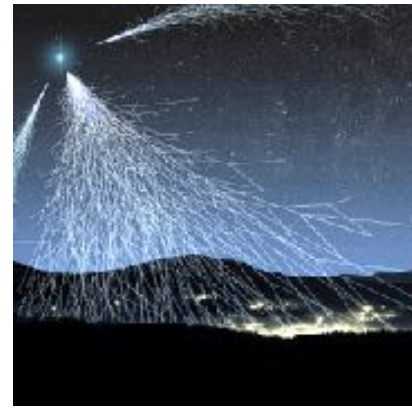
MAP THE POWER OF THE SUMMED WAVEFORM IN 4D



SHOWER PLANE



SHOWER TRACK

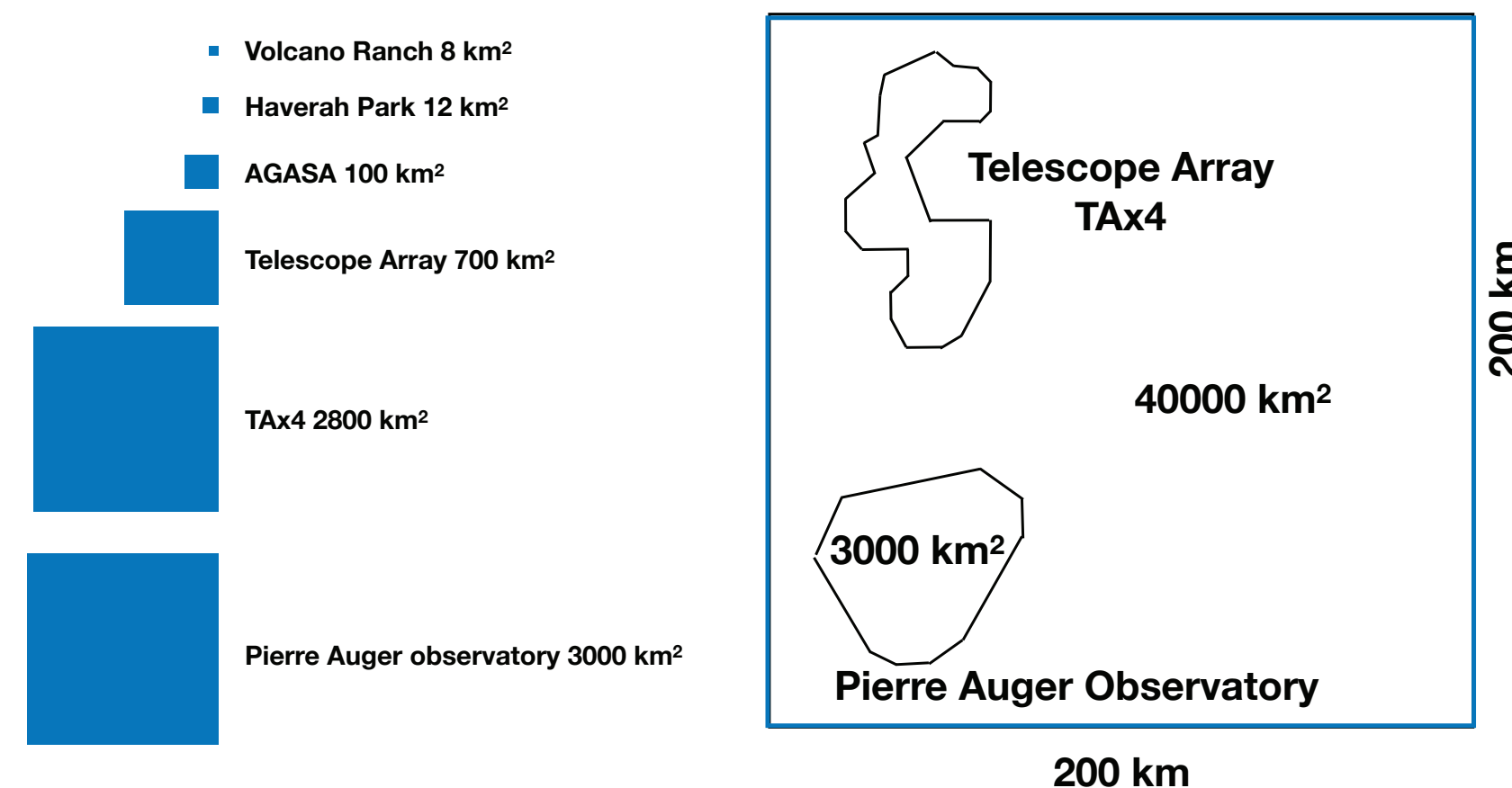


The Global Cosmic Ray Observatory

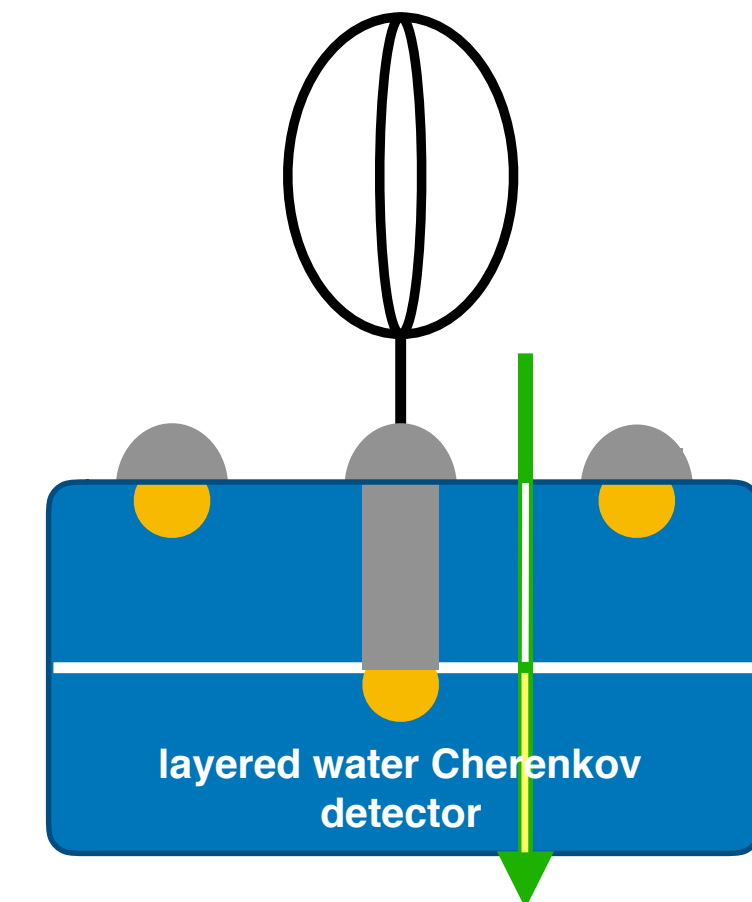
Multi-messenger astroparticle physics beyond 2030
protons, nuclei, gamma rays, neutrinos, (gravitational waves)

World-wide initiative to build next-generation CR observatory

At present working to define precise science case and detector layout, aiming at least for two sites (northern and southern hemisphere), covering at least 50 000 km²



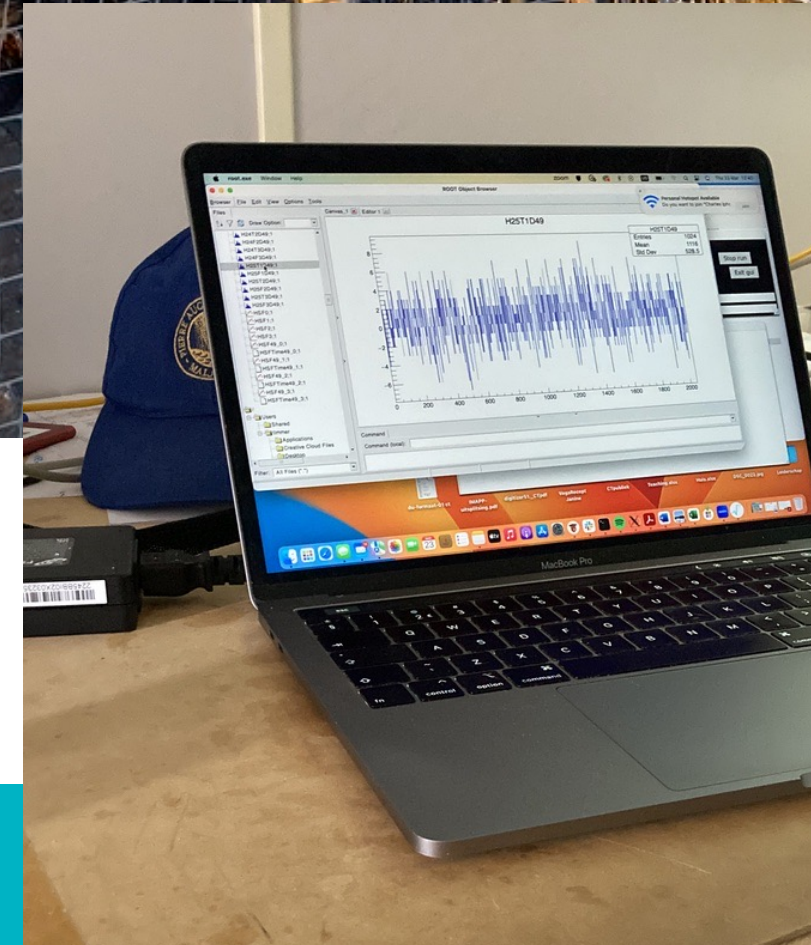
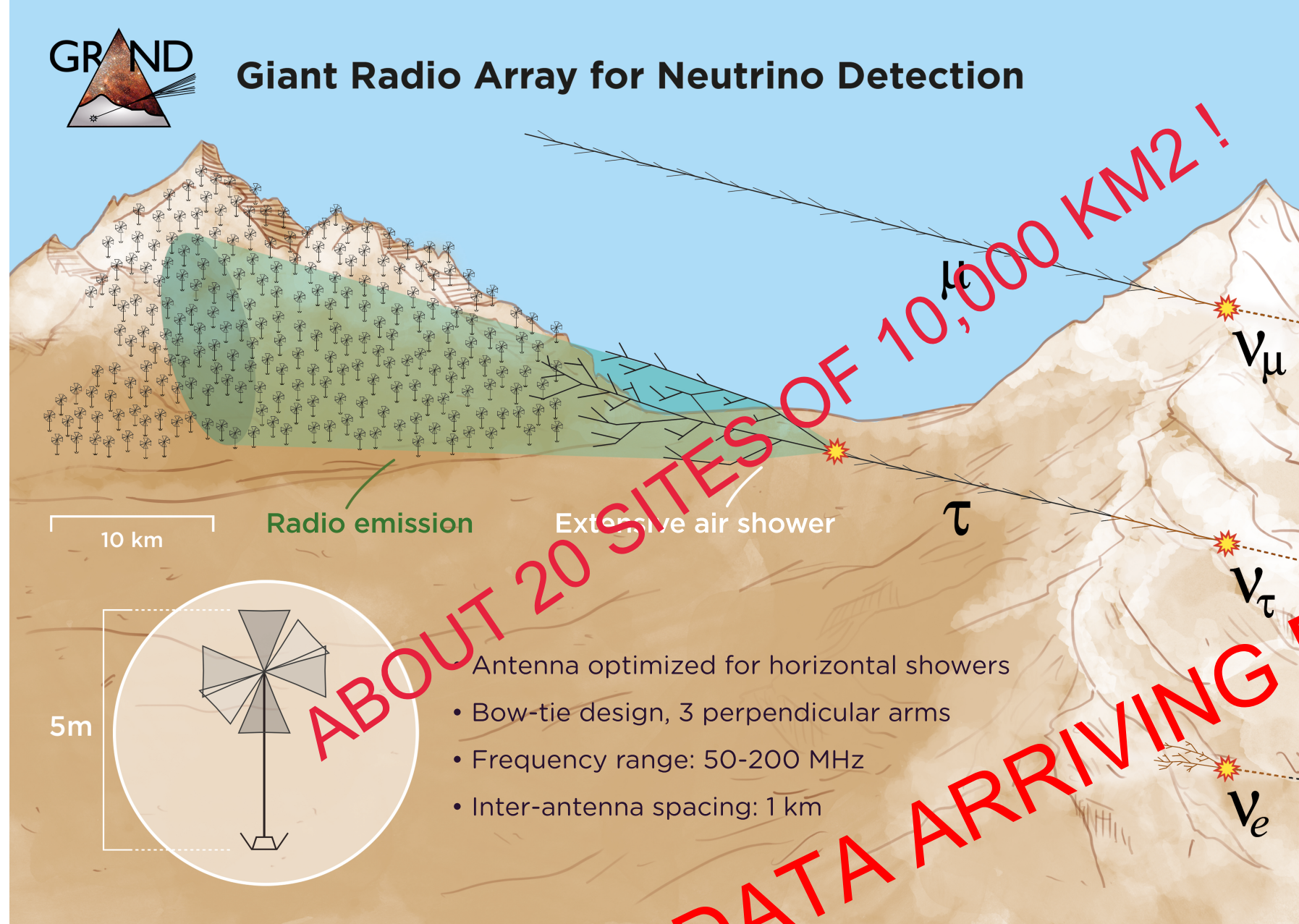
Discussing different detection concepts, like segmented water Cherenkov detectors combined with radio antennas, complemented by fluorescence detectors



GCOS homepage: <http://particle.astro.ru.nl/gcos>

upcoming workshop, Brussel, June 2023: <https://indico.ihe.ac.be/event/1729/>

GRAND



FIRST HARDWARE DEPLOYED AND FIRST DATA ARRIVING FROM CHINA AND ARGENTINA

NEXT

Much more about the Auger Radio detector by Mohit